Enhancement of the NearCoM Model for Nearshore Hydrodynamics

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LONG TERM GOAL

Our goal is to provide support for the end user community for the NearCoM model system, and to continue enhancement of NearCoM as a comprehensive model for processes in a range of nearshore environments. Enhancements would come in the form of

1. Code redesign and adoption of numerical schemes to provide for more efficient model operation on a range of computer platforms, including parallel environments,

2. Incorporation of improvements to the theoretical basis for processes described by existing modules,

3. Generalization of the Master Program environment to incorporate a wider range of process modules,

4. Better integration of the model with input from larger-scale models and measured data sources, and

5. Continued testing against available and future data sets.

OBJECTIVES

The objectives for this period of funding are to:

1. Fine tune the initial posting of online information and documentation for the NearCoM model.

2. Document (by means of a users manual and journal paper) a CFL-independent numerical scheme which has been developed for the Shorecirc model, and investigate the time-step limitations to be employed to obtain accurate results (relative to the existing predictor-corrector formulations) for wave-drive nearshore circulation.

3. Continue work aimed at coupling NearCoM to input boundary conditions provided by larger-scale models of the farfield, primarily SWAN and ROMS.

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APPROACH

To improve the computational efficiency of the NearCoM model, we focused on the development and tests of a CFL-free numerical scheme for the quasi-3D nearshore circulation module Shorecirc, which is the most time-consuming part of the standard NearCoM configuration. The mode-splitting technique (Shchepetkin and McWilliams, 2005, Casulli and Cheng, 1991) is applied to the curvilinear nearshore circulation equations (Shi et al., 2003) using the conventional two-step projection method. The resulting time difference equation for the vorticity mode includes lateral mixing terms, 3-D dispersion terms and wave forcing terms. It can be solved in an explicit scheme due to its slowly time-varying property. The gravity mode equations are further organized by substituting time-difference momentum equations into the continuity equation, which yields a single parabolic type equation with respect to surface elevation. The parabolic equation in curvilinear coordinates includes second order mixed derivative terms and advection-like terms. McKee et al.'s (1996) scheme is modified and used in solving the equation.

Various matching boundary conditions are implemented in the NearCoM modules in order to couple NearCoM to farfield data sources. Specifically, surface elevation and volume flux boundary conditions are developed for recasting larger scale circulation model (e.g., ROMS) output as NearCoM input, and the directional spectrum wave boundary condition in REFDIF-s is modified to match the output from the larger scale wave model-SWAN. An efficient moving shoreline technique is incorporated in the model according to Shi et al. (1998).

WORK COMPLETED

The NearCoM model was updated with the new CFL-independent numerical scheme implemented in the curvilinear version of the nearshore circulation module. Several tests were made on numerical stability, convergence rates and computational efficiency. The model is documented in two journal articles (Shi and Kirby, 2005, Shi et al., 2005, to be submitted) detailing the efficient numerical scheme and model testing against field data.

In the Sea Grant project related to this work, the updated NearCoM was coupled with the shelf-scale circulation model ROMS and shelf-scale wave model SWAN for predictions of waves and currents at Indian River Inlet, Delaware. The performance of the coupling system was evaluated based on computational efficiencies of the individual models. Boundary conditions required to match modules were tested in the operation of the coupled system based on the Model Coupling Environmental Library (MCEL).

In a recent collaboration with Dan Hanes at USGS, we have validated the circulation model with the new efficient scheme against field data in modeling of tidal and wave-induced currents in San Francisco Bight and the Ocean Beach coastal region. We also conducted a model/model comparison of computational efficiency between NearCoM and Delft3D (with 2D-mode) in the same computational domain. It was shown that NearCoM with the fast scheme is more computationally efficient when a high Courant number is adopted.

In the work associated with applications of NearCoM to the San Francisco Bight and Ocean Beach, the wave model SWAN has been modified and now may be utilized as a wave module in NearCoM. The NearCoM model with the SWAN-SHORECIRC combination was then used in both the large domain, covering the San Francisco Bight, and the small domain, including the Ocean Beach coastal area. The

large-domain NearCoM computes wave generation and propagation, and nearshore circulation induced by tides and river discharge. The small-domain NearCoM is nested in the large-domain NearCoM to predict nearshore waves and currents induced by both tides and waves. One-way coupling is carried out between the large-domain and small-domain NearCoM models. We have begun steps toward using the sediment module for the prediction of the erosional 'hot spots' on beaches along the Ocean Beach coast.

RESULTS

The convergence rates of the fast numerical scheme were evaluated in a case of wave evolution in a rectangular basin. Figure 1 shows the variation of logarithmic RMS differences of surface elevation with respect to grid spacing at different time steps. The averaged Cauchy convergence rates are 2.66, 2.25, 1.83 and 1.62 for Δt =0.01s, 0.1s, 0.3s, and 0.5s, respectively. The convergence rates are comparable to that from the predictor-corrector scheme used in the previous SHORECIRC (Shi et al., 2003).

The computational efficiency of the new scheme was evaluated in the coupling of NearCoM and large-scale models – SWAN and ROMS in the Sea Grant funded project. In the distributed model-coupling framework, the three models run on different Linux machines simultaneously and communicate to each other through a network-based CORBA technique. Because a high resolution grid was used for NearCoM, the efficiency of NearCoM directly affect the overall efficiency of the coupling system. Tests on tidal current simulations showed that the NearCoM with the previous explicit scheme causes 78% of idle time for SWAN and ROMS. When the new scheme was adopted, NearCoM had 75% of idle time waiting for SWAN and ROMS results. For simulations of wave-induced circulations, the Courant number is limited by the time resolution of infra-gravity waves. In most of the test cases, use of Courant numbers between 1 and 10 gives good resolution of nearshore circulation.

The model was applied to wave and current simulations in San Francisco Bight and the Ocean Beach coastal region. Figure 2 (a) and (b) show the generalized curvilinear grids for the San Francisco Bight model and the Ocean Beach model, respectively. Field observed time series of surface elevation and current velocity at the Golden Gate station are used for model validation. Figure 3 shows the model/data comparisons of surface elevation. The two numerical results with Courant number = 10 and 100, respectively, are basically identical. Both of the results agree well with the data. As shown in Figure 4, the NearCoM results of depth-averaged current velocity are compared to the data from ADCP near the Golden Gate bridge and the numerical results from Delft3D (2D mode). Both of the numerical results are in fairly good agreement with the data. The difference between the two numerical model results are small but can be identified. We suspect that the difference may be caused by different grid resolutions and model parameterizations used in the two models.

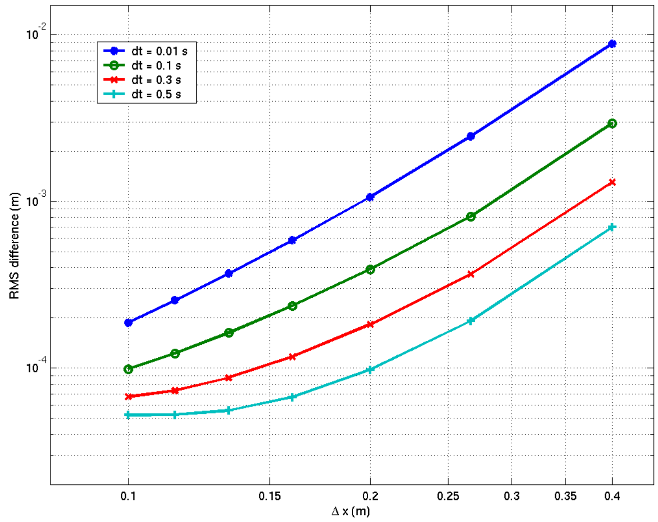

Figure 1. Convergence rates with grid refinement for new split-step numerical scheme for Shorecirc/NearCoM. Evaluation was based on the evolution of waves in a rectangular basin. The convergence rate is demonstrated by the RMS differences of simulated surface elevations at different time steps.

The nested small-domain NearCoM predicts waves and nearshore circulations induced by both tides and waves. Figure 5 gives the wave height distribution (left) and wave-induced longshore current (without input of tidal surface elevation at boundaries). The results will be compared to data when nearshore field measurements are conducted.

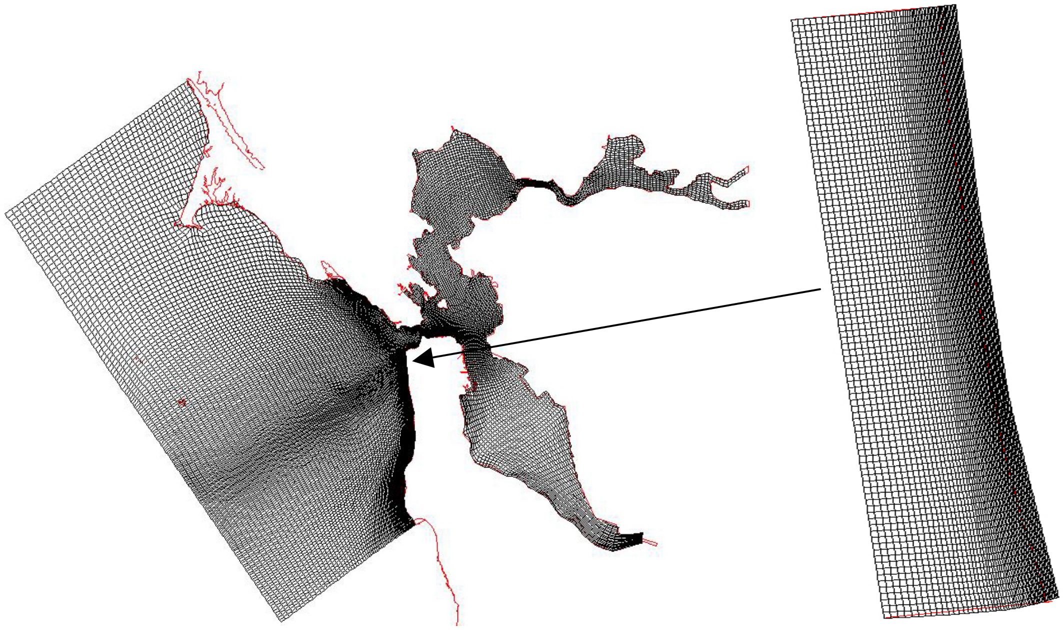

Figure 2

a) Grid for San Francisco Bight region (The grid spacing varies from 19m to 1,320m with the minimum spacing in the coastal regions and maximum at the offshore boundaries).

b) Grid for Ocean Beach region (minimum grid spacing is 5m)

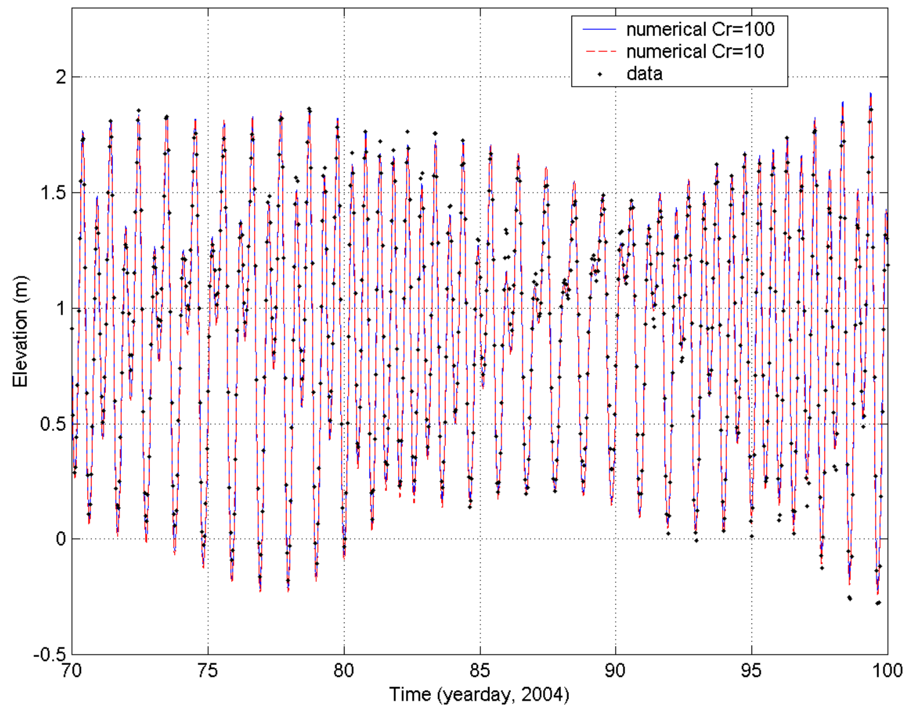

Figure 3. Model/data comparisons of surface elevation at Golden Gate Station. Numerical results obtained from Courant number = 10 and 100 are identical and both of them agree with data.

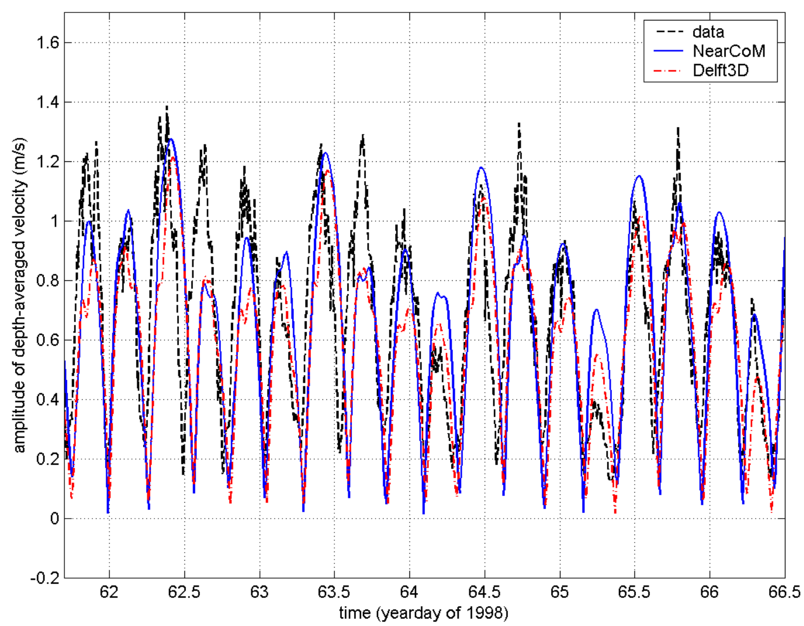

Figure 4. Model/data comparisons of depth-averaged current velocity at the location near Golden Gate Bridge.

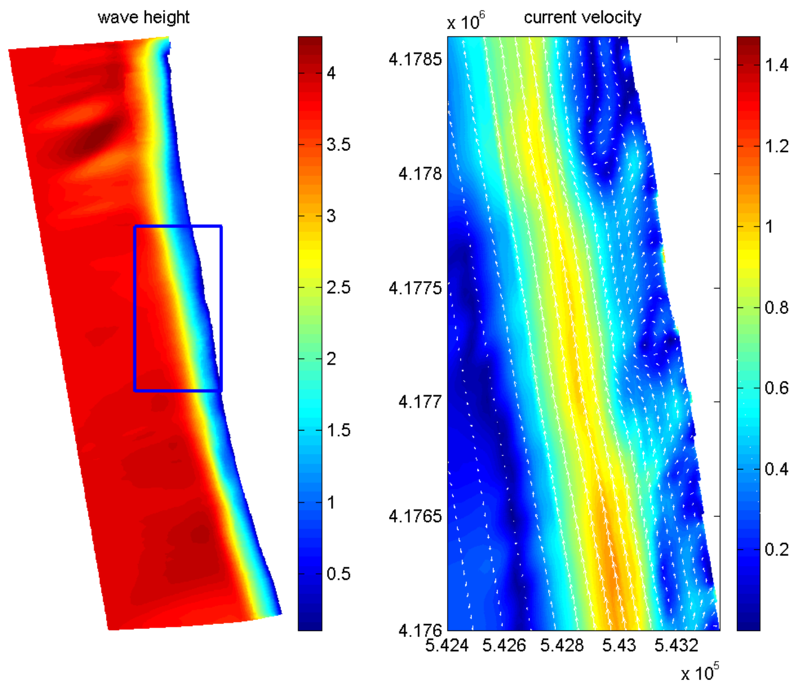

Figure 5. Distribution of significant wave height (left) and wave-induced longshore currents (right) from the small-domain NearCoM model. Wave conditions: 4m significant wave height, 40 degree wave direction (0 degree points east), 15 s peak period and Jonswap spectrum at the large domain boundaries. Wind condition: 10 m/s South-West.

IMPACT/APPLICATIONS

It is believed that the present work is an important step toward the long-term goal of efficient modeling of nearshore waves, circulations and sediment transport. The studies on model coupling mechanism and matching boundary conditions have made a connection between large-scale ocean models and NearCoM and will be beneficial to the multi-scale modeling of ocean and coastal processes.

RELATED PROJECTS

"Coupling of inner shelf ocean models and a nearshore community model for wave and current prediction at tidal inlets". PI: James T. Kirby, Co-PI: Fengyan Shi (Sponsor: NOAA Sea Grant)
"Study on erosional hot spots at Ocean Beach". PI: Dan Hanes. (Sponsor: USGS)

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PUBLICATIONS

Shi, F. and Kirby, J. T., "An efficient mode-splitting method for a curvilinear nearshore circulation model", to be submitted to Journal of Computational Physics, 2005.

Shi, F., Hanes, D., Kirby, J. T., "Extension of the Nearshore Community Model (NearCoM) for multi-scale applications – a case study at San Francisco Bight and its open coastal areas", to be submitted to Ocean Modeling, 2005.